

Initial Study Characterization of Residual Noise on a Phantom in Simultaneous EEG-fMRI Using Carbon Wire Loops

Gracia Khoury¹, Giulia Lioi², Frédéric Grouiller^{3,4}, and Claire Cury¹

¹Univ Rennes, CNRS, Inria, Inserm, IRISA UMR 6074, Empenn - ERL U 1228, 35000 Rennes, France

²IMT Atlantique, Lab-STICC UMR CNRS 6285 F-29238, Brest, France

³CIBM Center for Biomedical Imaging, Geneva, Switzerland

⁴Department of Radiology and Medical Informatics, Geneva University Hospitals, Geneva, Switzerland

June 21, 2026

1 Introduction

Simultaneous acquisition of EEG-fMRI signals is a neuroimaging technique that aims to combine the high temporal resolution of EEG and the high spatial resolution of fMRI to obtain an accurate and dynamic mapping of brain activity. This multimodal approach is particularly promising for applications such as neurofeedback [1], where real-time monitoring and modulation of neural activity can support personalized brain rehabilitation. This type of acquisition, while improving data resolution, introduces additional artefacts in the EEG recordings. This is due to the presence of the MRI magnetic field B_0 and the switching of gradients known as the gradient artifact, which has a deterministic nature [2], since the EEG is synchronized with the MRI clock. In addition to that, noise generated by cardio-ballistic activity, human involuntary movements in the MRI bore, or vibrations due to the helium pump [3], are collectively referred to as motion artifacts. They introduce noise to the EEG signal because a closed electrical circuit in a magnetic field induces an electric current (Faraday's law of electromagnetic induction). The activity of motion artifacts can be tracked using carbon-wired loops (CWL). To have a clean signal, a regression is applied on the EEG signal using those recordings [4].

However, it is unknown whether the regression distorts the EEG signal, which would be quite concerning in a neurofeedback context, as it can remove or modify important neuronal data in the EEG bands delta, theta, and alpha. The aim of this study is to perform an initial characterization of the EEG signal after applying a CWL regression. We use a phantom acquisition in order to remove any motion-related artifacts generated by small involuntary movements of the participant and cardio-ballistic activity, and to observe the impact of the CWL regression on the acquired EEG signal without additional confounding factors.

2 Method

We designed a protocol to measure any non-motion artifact on EEG signals inside the MRI, by using a 17cm diameter MRI sphere phantom. Data were acquired on a 3T MRI scanner (Cima X, Siemens Healthineers), using a 64-channel MR-compatible EEG cap equipped with an ECG channel and four CWL from BrainProducts. The phantom is positioned in the MRI at the same location where the head of the participant is usually placed. We acquired a 4-minute EEG recording without fMRI sequence and an EEG recording with an fMRI sequence. In both recordings, the Helium pump was switched on. The data were then processed using Brain Vision Analyzer. All EEG signals were down-sampled at 500 Hz and filtered with a high-pass filter at 0.1 Hz to remove slow artifact amplitude modulation [5]. An average artifact subtraction was applied to the EEG-fMRI run to remove the gradient artifact. Then, a CWL regression was applied to both runs. We computed the power spectral density and estimated its mean value and standard deviation across all EEG electrodes with and without fMRI acquisition. Ground-truth theoretical signals were generated to mimic what should be the EEG signals of the phantom after artefact correction. These theoretical signals were generated by averaging 100 independent realizations of a flat signal corrupted by additive white Gaussian noise ($\mu = 0, \sigma = 1$ mV, $t = 240$ s, $f = 500$ Hz). All PSD are computed using Welch's method as implemented in MNE-Python.

3 Results

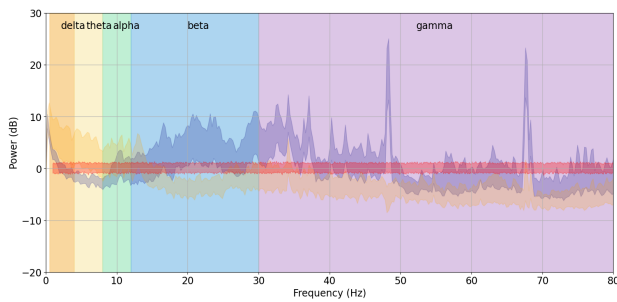


Figure 1: EEG-fMRI acquisition. Mean $\pm$ std of EEG signals' PSD before (in blue) and after CWL regression (in yellow) vs mean $\pm$ std of theoretical signal (in red).

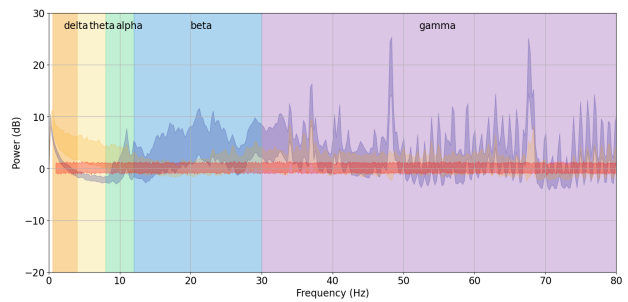


Figure 2: EEG recording within fMRI tube. Mean and std of EEG signals' PSD before (in blue) and after CWL regression (in yellow) vs mean and std of theoretical signal (in red).

Results indicate that after the CWL regression with or without fMRI sequence (Figures 1 and 2), noise in the high frequencies was indeed reduced, but noise in the lower frequencies was also modified. The regression introduced noise in the lower frequencies in the bands delta, theta, and alpha. For the EEG-fMRI acquisition in the fMRI sequence, the correction for the Beta and Gamma bands are closer to the theoretical signals in red (Figure 2). The artefact of the Helium pump is also visible. Indeed, before applying CWL regression, there was a peak at 47Hz that was attenuated after applying the regression. This shows that the Helium pump artefact is regressed out by the CWL that captured this artefact.

4 Conclusions

The observations showed that, after regression, the noise in high frequencies was attenuated. In contrast, the noise in the low frequencies was also affected: the regression introduced noise in the low frequencies, which would be very concerning for neurofeedback tasks, as the EEG neurofeedback scores are often derived from changes in the delta, theta, and alpha frequency bands. These findings highlight the need for a more precise characterization of MRI-induced EEG artifacts and demonstrate that CWL regression is not a trivial correction procedure. Future work will focus on understanding the mechanisms by which CWL regression distorts EEG signals. To this end, we plan to conduct additional experiments using both physical and human phantoms across different MRI scanners, allowing us to assess the reproducibility of these effects and better characterize scanner-specific sources of artifact and distortion.

References

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